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the end of the article**GENERAL & APPLIED ECONOMICS | LETTER****A simple framework for analysing the impact of economic growth on non-communicable diseases**Ivan K. Cohen¹, Fabrizio Ferretti^{2*} and Bryan McIntosh³

Abstract: Non-communicable diseases (NCDs) are currently the leading cause of death worldwide. In this paper, we examine the channels through which economic growth affects NCDs' epidemiology. Following a production function approach, we develop a basic technique to break up the impact of economic growth on NCDs into three fundamental components: (1) a resource effect; (2) a behaviour effect; and (3) a knowledge effect. We demonstrate that each of these effects can be measured as the product of two elasticities, the output and income elasticity of the three leading factors influencing the frequency of NCDs in any population: health care, health-related behaviours and lifestyle, and medical knowledge.

Subjects: Development Economics; Economics; Global Health; Population Health**Keywords:** economic growth; Engel's functions; health production function; non-communicable diseases; social determinants of health**JEL classifications:** I1; I15**1. Introduction**

Chronic non-communicable diseases (NCDs)—once considered “diseases of affluence” that affect elderly and wealthy people in developed regions—are currently the leading cause of death and disability worldwide (World Health Organisation [WHO], 2014). The global epidemic of NCDs is widely acknowledged as a major threat, not only to human health, but also to health systems and economic growth (Bloom et al., 2011).

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PUBLIC INTEREST STATEMENT

This paper provides a simple but coherent framework to describe and measure the impact of economic growth on mortality due to chronic non-communicable diseases (NCDs). NCDs, once considered *diseases of affluence*, are currently a major public health problem and the cause of about two-thirds of global deaths. The burden of NCDs is remarkable in all the world regions and is projected to increase during the next years (even in low- and middle-income countries). This global epidemic is acknowledged as a major threat to health systems and economic growth. The research to date has tended to focus on the economic burden of NCDs on individuals and countries. In this paper, we reverse the perspective by examining the main channels through which economic growth affects NCDs' epidemiology. The study identifies three fundamental forces: (1) a resource effect; (2) a behaviour effect; and (3) a knowledge effect.

There is a complex relationship between economic growth and NCDs. Strengthening the growth process does not automatically decrease the burden of NCDs. Sustained economic growth, however, tends to create the necessary conditions to tackle NCDs and therefore to improve human health (Weil, 2012). Basically, along with education, health is a crucial dimension of human capital, and human capital plays a key role in fostering economic growth. In turn, economic growth allows a society to decrease both the incidence and the mortality of NCDs by allocating more and better resources to health education, health care and medical research (Bloom & Canning, 2000).

Both directions of this interdependent relationship are at the heart of our understanding of the economic and social determinants of health (Canning, Bloom, Jamison, & Ruger, 2012). The emerging challenge of NCDs has stimulated comprehensive research about the economic burden of these pathologies at both the micro- and the macroeconomic level (Engelgau, Rosenhouse, El-Saharty, & Mahal, 2011; Suhrcke, Nugent, Stuckler, & Rocco, 2006). In this paper, we reverse this perspective by examining the impact of economic growth on NCDs' epidemiology. Our focus on NCDs is motivated by the fact that today "The world has reached a decisive point in the history of NCDs and has an unprecedented opportunity to alter its course ... The world now has a truly global agenda for prevention and control of NCDs, with shared responsibilities for all countries based on concrete targets" (Chan, 2014, p. VII).

In economics, it is usual to model the population health outcome as a function of the causes of health using a production function (Grossman, 1972). Following this standard approach, we aim to develop a basic technique to break up the impact of economic growth on NCDs into three fundamental components: (1) a "resource effect"; (2) a "behaviour effect"; and (3) a "knowledge effect". Within this simple framework, each of these effects is the product of two elasticities: the output and income elasticity of the three leading factors influencing the frequency of NCDs in any population, namely health care, health-related behaviours and lifestyle, and medical knowledge.

The remainder of the paper is structured as follows. In Section 2, we briefly review the concept of the health production function. In Sections 3 and 4, we discuss the major effects of economic growth on the arguments of the health production function. In Section 5, we attempt to decompose and measure the channels through which the growth process affects the mortality rate due to NCDs. Finally, Section 6 concludes the paper with an elementary numerical example for explanatory purposes and some comments about the strengths and limitations of the proposed approach.

2. The production of health

From an economic standpoint, health can be regarded as a durable good: an output that people are able to produce by combining a set of appropriate medical and non-medical inputs for a given state of medical knowledge. A "production function for health" relates the various inputs to the output and describes the society's available health technology (Folland, Goodman, & Stano, 2013).

Within this framework, let us denote by H the age-standardized mortality rate caused by the leading NCDs (cancers, diabetes, respiratory and cardiovascular diseases, etc.). Surely, H is influenced by several different and interrelated factors. For any given state of medical knowledge (M), however, a health production function for H has to be based on at least two fundamental health inputs: health care (HC) and people's health-related behaviours, habits and living conditions (HB) (Sloan & Hsieh, 2012).

For our purposes, it is convenient to express the relationship between these health inputs and the population health outcome mathematically, as follows:

$$H = f(HC, HB, M) \quad (1)$$

where HC is a measure of the amount of resources that the society devotes to health care to tackle NCDs (i.e. the real per capita expenditure on health care for NCDs), while HB is a measure of the average population's exposure to environmental and lifestyle risk factors for NCDs (i.e. an index that

summarizes all modifiable behaviours and conditions associated with NCDs, taking a value between 0 and 1—that is, a “perfectly healthy” and a “perfectly unhealthy” situation, respectively). Finally, M is a measure of the existing medical knowledge available to prevent and cure NCDs (i.e. the current stock of ideas and practices in this field of medical science).

This basic production function simply states that, given M , each society can improve the population’s health status either by changing the resource allocation or by affecting people’s lifestyle and living environment. In particular, the negative sign below HC and the positive sign below HB in Equation 1 reflect the fact that, *ceteris paribus*—that is, given the genetic characteristics of the population under study and holding constant all other cultural, economic and social factors that influence health—more resources and fewer exposures (i.e. better health-related behaviours, habits and living conditions) exert positive effects on health and thereby lower the age-standardized mortality rate due to NCDs.

Finally, medical knowledge changes in response to breakthroughs in science and technology. A flow of new ideas increases the stock of existing knowledge. According to Equation 1, as medical science progresses, *ceteris paribus*, more health can be produced for any given levels of HC and HB , again leading to a decrease in H (this is why a negative sign also appears under M in the production function).¹

3. The health production function during economic growth

In the short run (say, from year to year), the arguments of the health production function are likely to be nearly constant or to undergo only minor changes. On the other hand, in the long run (say, from decade to decade), economic growth tends to produce deep transformations in both health inputs and medical knowledge. More particularly, at a macroeconomic level, changes in HC , HB and M are primarily due to structural changes resulting from the interaction of factors operating on the demand and the supply side of the economy, respectively (López-Casasnovas, Rivera, & Currais, 2005).

On the demand side, the individual and collective preferences about health status and the satisfaction of health needs are not constant during growth. As the real per capita income increases, people modify both their consumption patterns and their approval of the public health policies. As a result, the population’s demand for health care and health programmes changes, in both quantitative and qualitative terms, and so does the population’s demand for health-related goods (i.e. each commodity or service that yields utility, but also affects—positively or negatively—health conditions: food, tobacco and alcohol, environmental quality, etc.) (McQueen, 2013).

On the supply side, the technology available to produce health generally reflects the society’s level of economic development. Although income per capita is not the only or best measure of genuine economic progress, superior medical techniques, especially better pharmacological and surgical treatments, and new tools for early diagnosis and screening usually accompany economic growth in a “virtuous cycle” in which growth promotes M and in turn M reinforces the growth process through its effects on H (Sachs, 2001; WHO, 2014). An unequal income distribution can have adverse effects on people’s access to better health care (Biggs, King, Basu, & Stuckler, 2010; Ecob & Smith, 1999). However, in a growing economy, medical improvements tend—in the very long run—to become available to larger proportions of the population (either directly by the market mechanism or indirectly through public provision), enhancing the health-related quality of life (Cutler, Deaton, & Lleras-Muney, 2006; Deaton, 2008; Pritchett & Summers, 1996).

The demand-side structural changes affect preferences and thus they influence primary HC and HB , while those relative to the supply side involve technology and thus they influence M foremost. A useful way to capture these complex impacts of economic growth on health inputs and medical knowledge is to make explicit the dependence of HC , HB and M on income per capita, by using three Engel-type² (Chai & Moneta, 2010) basic functions, as follows:

$$HC = HC(Y)_{+} \quad (2)$$

$$HB = HB(Y)_{+/-} \quad (3)$$

$$M = M(Y)_{+} \quad (4)$$

in which Y denotes the average real income per person (i.e. the gross domestic product (GDP) per capita in constant prices). Equations 2 and 4 describe the positive relationships between growth and health expenditure and between growth and medical technology, respectively. They simply state that as the real average GDP increases, more resources per capita are spent on health care to prevent and cure NCDs and medical knowledge about NCDs progresses. Conversely, the alternative positive and negative signs under Y in Equation 3 express a theoretically ambiguous relation between economic growth and the average population's exposure to environmental and lifestyle risk factors for NCDs. We discuss some features of Equation 3 in the following section.

4. Health-related behaviours during economic growth

The leading NCDs have two basic characteristics in common: a complex aetiology and multiple risk factors. In the literature, the interaction between the inborn genetic characteristics of individuals and numerous external agents—tobacco use, alcohol abuse, an unhealthy diet, a lack of physical activity, air pollution, chronic infection and so forth—is well documented (Bonita, Beaglehole, & Kjellström, 2006).

A specific feature of these external agents is that they are avoidable or at least modifiable. The exposure to NCDs' external agents therefore changes when people modify their lifestyle and living environment, either directly by individual choices (such as variations in tobacco consumption and eating patterns) or indirectly through collective choices (such as improvements in environmental quality and workplace conditions) (Yach, Mensah, Hawkes, Epping-Jordan, & Steyn, 2012).

From the consumption perspective, goods and services are indeed categorized according to a hierarchical structure, determined by several biological, cultural and social factors (Argyrous, 2002; Pasinetti, 1981). Thus, as income increases, the tendency is not to expand the demand of each good and service proportionally. Rather, there are further income threshold levels at which tastes and preferences switch and people start following new consumption patterns (Chai & Moneta, 2013). These structural changes affect the exposure to external agents, either in a positive or in a negative direction, that is, towards a more or less risky situation (thus shifting HB closer to 1 or 0, respectively).

For instance, in its initial stages, the growth process may tend to push populations towards unhealthy lifestyles, characterized by an increasing prevalence of smoking, excessive alcohol intake and quantitatively/qualitatively incorrect nutrition (such as the routine consumption of animal fat, protein and calorie-dense foods) (Popkin, 2006). In these circumstances, economic growth is also driven by industrialization processes—usually based upon highly polluting production methods—which typically take place in unsafe and harmful working environments. In its later stages, however, economic growth tends to strengthen the population's concerns about the health consequences of private and public choices. As incomes rise, health becomes more and more important in people's hierarchy of needs and wants. The market demand for health-related goods and services (and the political demand for better living and working conditions) may thereby evolve in the direction of healthier individual and collective lifestyles (Jemal, Center, De Santis, & Ward, 2010; Setterfield, 2002).

5. Economic growth and NCDs: An elasticity approach

The income elasticity of a population's health conditions ($E_{H,Y}$) is commonly used to summarize and measure the impacts of economic growth on people's health (Bishai & O'Neil, 2012). Specifically, $E_{H,Y}$ is the percentage change in a certain measure of health status—here, the age-adjusted

mortality rate due to NCDs—in response to a given percentage change in real income per capita. That is, $(\Delta H/H)/(\Delta Y/Y)$ or more usefully:

$$E_{H,Y} = \frac{dH}{dY} \times \frac{Y}{H} \quad (5)$$

where the coefficient $E_{H,Y}$ is therefore a pure number that describes how much the health status responds to a change in income.

Starting from Equation 5, the concept of the health production function can be developed into a basic framework to investigate the channels through which economic growth affects NCDs. Specifically, by replacing all the arguments of Equation 1 with their expressions from Equations 2, 3 and 4 gives:

$$H = f[HC(Y), HB(Y), M(Y)] \quad (6)$$

where H is a function of one variable (i.e. it is a function of three functions, all of which have the same argument: the real GDP per capita). Thus, by applying the chain rule to Equation 6, we obtain:

$$\frac{dH}{dY} = \frac{\partial H}{\partial HC} \times \frac{dHC}{dY} + \frac{\partial H}{\partial HB} \times \frac{dHB}{dY} + \frac{\partial H}{\partial M} \times \frac{dM}{dY} \quad (7)$$

Thereby, given that $E_{H,Y}$ is the product of dH/dY times the income–health ratio Y/H , we can write Equation 5 as follows:

$$E_{H,Y} = \left(\frac{\partial H}{\partial HC} \times \frac{dHC}{dY} + \frac{\partial H}{\partial HB} \times \frac{dHB}{dY} + \frac{\partial H}{\partial M} \times \frac{dM}{dY} \right) \times \frac{Y}{H} \quad (8)$$

or, equivalently, by expanding this equation for Y/H , $E_{H,Y}$ becomes:

$$E_{H,Y} = \left(\frac{\partial H}{\partial HC} \times \frac{dHC}{dY} \right) \times \frac{Y}{H} + \left(\frac{\partial H}{\partial HB} \times \frac{dHB}{dY} \right) \times \frac{Y}{H} + \left(\frac{\partial H}{\partial M} \times \frac{dM}{dY} \right) \times \frac{Y}{H} \quad (9)$$

Finally, for our purposes, the income–health ratio can be more usefully written with one of the three following identities:

$$\frac{Y}{H} \equiv \frac{Y}{HC} \times \frac{HC}{H} \equiv \frac{Y}{HB} \times \frac{HB}{H} \equiv \frac{Y}{M} \times \frac{M}{H} \quad (10)$$

so that replacing Y/H in the first, second and third addends of Equation 9, with its corresponding expression taken from Equation 10, gives:

$$E_{H,Y} = \frac{\partial H}{\partial HC} \frac{HC}{H} \times \frac{dHC}{dY} \frac{Y}{HC} + \frac{\partial H}{\partial HB} \frac{HB}{H} \times \frac{dHB}{dY} \frac{Y}{HB} + \frac{\partial H}{\partial M} \frac{M}{H} \times \frac{dM}{dY} \frac{Y}{M} \quad (11)$$

where $E_{H,Y}$ is still the sum of three addends, as in Equation 7, but each of these addends is now the product of two elasticity coefficients: namely an output elasticity and an income elasticity (the multiplicand and multiplier of each term of the right-hand side of Equation 11, respectively).

Equation 11 has a simple interpretation. Specifically:

- the first term is the elasticity of the population's health status with respect to health care ($E_{H,HC}$) times the income elasticity of HC ($E_{HC,Y}$). The product of these coefficients ($E_{H,HC} \times E_{HC,Y}$) captures the “resource effect” of economic growth on people's health;

- the second term is the elasticity of the population's health status with respect to health-related behaviours, habits and living conditions ($E_{H,HB}$) times the income elasticity of HB ($E_{HB,Y}$). The product of these coefficients ($E_{H,HB} \times E_{HB,Y}$) captures the “behaviour effect” of economic growth on people's health;
- finally, the third term is the elasticity of the population's health status with respect to medical knowledge ($E_{H,M}$) times the income elasticity of M ($E_{M,Y}$). The product of these coefficients ($E_{H,M} \times E_{M,Y}$) captures the “knowledge effect” of economic growth on people's health.

We can therefore rewrite Equation 11 in an insightful way, as follows:

$$E_{H,Y} = \underbrace{E_{H,HC} \times E_{HC,Y}}_{\text{resources}} + \underbrace{E_{H,HB} \times E_{HB,Y}}_{\text{behaviours}} + \underbrace{E_{H,M} \times E_{M,Y}}_{\text{knowledge}} \quad (12)$$

where the complex effects of economic growth on health are broken down into their three fundamental components: (1) resources; (2) behaviours; and (3) knowledge.

In particular, the magnitude of changes in HC , HB and M due to economic growth is measured by an income elasticity coefficient ($E_{HC,Y}$, $E_{HB,Y}$ and $E_{M,Y}$ respectively), whereas the magnitude of changes in the population's health status due to changes in HC , HB and M is measured by an output elasticity coefficient ($E_{H,HC}$, $E_{H,HB}$ and $E_{H,M}$ respectively). The product of each income elasticity times its own output elasticity gives the size of the partial effect on people's health of the corresponding health determinant—that is, the separate effect on health of resources, behaviours and knowledge, respectively—and by summing up these three effects, we put back together the income elasticity of the population's health status (i.e. the reactivity of the NCDs' mortality rate to economic growth).

Finally, a general feature of NCDs is the existence of a delay between the exposure to risk factors, the illness's onset, the health care received and the mortality due to the disease. That is, “today's mortality is affected by yesterday's exposure, health care, and knowledge, and today's exposure, health care, and knowledge will affect tomorrow's mortality”, *ceteris paribus*. In other words, there is a temporal lag between H and the independent variables of the health production function (especially for HB). Consequently, Equation 12 should be read as follows: “during period t , changes in Y lead to changes in M , HC , and—for any given cohort of the population under study— HB ; in turn, changes in M , HB , and HC lead in each cohort to changes in H during period t_{+n} ”.

6. Discussion and conclusions

Measuring the stock of medical knowledge, although conceptually plausible, is in fact extremely difficult. The lack of a reliable quantitative measure of M , however, helps in illustrating an interesting feature of this framework. Equation 12 may be reorganized as follows:

$$E_{H,M} \times E_{M,Y} = E_{H,Y} - \left(\underbrace{E_{H,HC}}_{\text{technology}} \times \underbrace{E_{HC,Y}}_{\text{preferences}} + \underbrace{E_{H,HB}}_{\text{biology}} \times \underbrace{E_{HB,Y}}_{\text{preferences}} \right) \quad (13)$$

where the “knowledge effect” is now obtained as a residual after subtracting from the income elasticity of the population's health status ($E_{H,Y}$) the effects due to resources and behaviours ($E_{H,HC} \times E_{HC,Y}$ and $E_{H,HB} \times E_{HB,Y}$), which are both—at least theoretically—observable and measurable.

In Equation 13, we also highlight the fundamental determinants of the resource and behaviour effects. On the one hand, the reactivity coefficients of health care and health-related behaviours with respect to income ($E_{HC,Y}$ and $E_{HB,Y}$) are Engel's elasticities: they tell us how much HC and HB respond to a 1% change in Y . The evolution of these coefficients during economic growth is primarily driven by the changing structure of people's preferences as consumers and citizens.

On the other hand, the reactivity coefficients of health status with respect to health care and to health-related behaviours ($E_{H,HC}$ and $E_{H,HB}$) are output elasticities: they tell us how much H responds to a 1% change in HC and HB , respectively. These two coefficients form the supply-side channel of the model, and their evolution is subject to the technological and biological constraints that characterize the health production process.

An elementary numerical example—with hypothetical and simplified data—may help in discussing the strengths and limitations of Equation 13 as a sort of “pedagogical tool” to decompose the impact of economic growth on NCDs’ mortality rate. Let us consider, for instance, the US population, in which the age-adjusted mortality rate caused by the main cardiovascular diseases (CVDs) declined by about 50% between the early 1980s and the late 2000s (National Center for Health Statistics, 2011). During the same period, the US GDP per capita rose by about 60% in constant prices (Council of Economic Advisers, 2012). These data imply an income elasticity of health status ($E_{H,Y}$) of around -0.83 .

This sharp decline in mortality was accompanied by changes in health care, health-related behaviours and medical knowledge. An educated guess for the income and output elasticities of health care and health-related behaviours, based upon several economic and epidemiological studies on the US economy, might be around $+1.5$ and -0.05 for $E_{HC,Y}$ and $E_{H,HC}$ (Miller, Hughes-Cromwick, & Roehrig, 2011; Thornton, 2002) and 2.5 and -0.16 for $E_{H,HB}$ and $E_{HB,Y}$ (Ergin, Muntner, Sherwin, & He, 2004; Ford & Capewell, 2011; Gregg et al., 2005), respectively.

Putting these figures into Equation 13 gives:

$$\underbrace{E_{H,M} \times E_{M,Y}}_{\text{knowledge}} = \underbrace{E_{H,Y}}_{-0.83} - \underbrace{[E_{H,HC} \times E_{HC,Y}]}_{\substack{\text{resources} \\ -0.075}} + \underbrace{[E_{H,HB} \times E_{HB,Y}]}_{\substack{\text{behaviours} \\ -0.40}} \quad (14)$$

that is, a “knowledge effect” of around 0.35. In summary, the “behaviour effect” explains approximately half of the current decline in H . The relatively low elasticity of health-related behaviours to income—the reduction in three of the main CVD risk factors (i.e. total cholesterol level, blood pressure and smoking habits)—that occurred during the last few decades (Ford & Capewell, 2011) is compensated for by a relatively high elasticity of the health outcome to this reduction in major risk factors. On the other hand, despite the high reactivity of health care expenditure to income, the inelastic response to H to more resources (i.e. the so-called “flat-of-the-curve medicine” hypothesis) generates a resource effect that accounts for less than 10% of the total reduction in the CVDs’ mortality rate. Thus, advances in medical knowledge and changes in health-related behaviours, driven by the growth process, are the major forces that influenced the recent evolution of mortality due to CVDs in the US population (Ford et al., 2007).

In other words, this sort of “accounting framework” can be utilized either to describe or to measure how economic growth tends to affect NCDs’ mortality rate, through its influence on the main determinants of health. A serious limitation of this latter use is the availability of an appropriate information base. To decompose $E_{H,Y}$ into its fundamental components, we need: (1) to collect data on many economic and epidemiological variables; (2) to compute a complex index for HB (Ford, Li, Zhao, Pearson, & Capewell, 2009; Salvador-Carulla et al., 2013); and (3) to estimate the impact of HC , HB and M on NCDs’ mortality rate, holding all other factors constant. As illustrated by ongoing research (National Research Council, 2010; Organisation for Economic Co-operation & Development, 2011), however, measuring the medical and non-medical determinants of people’s health and assessing their isolated impact on the health status are difficult tasks to perform.

In spite of these empirical weaknesses, this framework is flexible enough to be applied to examine, at an abstract level, the impact of economic growth on a population's health in a wide range of situations. A closer look at Equations 12 and 13 suggests that this approach is suitable for application to other kinds of pathologies, as well as to several different measures of health conditions or disease frequencies. For instance, we can measure with H the age-standardized incidence rate of a communicable disease in a developing country, and we can use Equations 12 and 13 to investigate the channels through which economic growth affects H by way of changes in people's health-related behaviours, in government spending on public health, and in the international transfer of medical knowledge.

Finally, a potential insightful use of this framework is the analysis of the impact of the *Great Recession* on the future population health status in developed economies (Grusky, Western, & Wimer, 2011). A prolonged and deep recession, accompanied by drastic cuts in public health expenditure and by increasing income inequality—as recently experienced by some European countries—will ultimately affect NCDs' epidemiology. We are able to investigate the impact of the recession on the future overall health of populations, especially through the negative effect of a decreasing real per capita income on changes in private and public resource allocation to health care and health-related behaviours.

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Notes

1. A variety of measures are commonly used to characterize the overall health of populations. The dependent variable in the health production function can be a measure of disease frequencies (such as the incidence or prevalence rate), of health outcome (such as the mortality or morbidity rate and life expectancy), or even of the duration of life combined with some notion of its quality (such as the quality-adjusted life years (QALYs) or disability-adjusted life years [DALYs]). We focus on the mortality rate only to keep the model as simple as possible (Breyer, Kifmann, & Zweifel, 2009).
2. In a narrow sense, an Engel's function shows the relationship between the quantity demanded of a single good (or the expenditure on a set of goods) and income, holding prices constant (Engel, 1895; Lewbel, 2006).

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